Passive Smoking on Commercial Airline Flights

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In-flight exposure to nicotine, urinary cotinine levels, and symptom self-reports were assessed in a study of nine subjects (five passengers and four attendants) on four routine commercial flights each of approximately four hours' duration. Urine samples were collected for 72 hours following each flight. Exposures to nicotine measured during the flights using personal exposure monitors were found to be variable, with some nonsmoking areas attaining levels comparable to those in smoking sections. Attendants assigned to work in nonsmoking areas were not protected from smoke exposure. The type of aircraft ventilation was important in determining the levels of in-flight nicotine exposure. The environmental tobacco smoke levels that occurred produced measurable levels of cotinine (a major metabolite of nicotine) in the urine of passengers and attendants. Passengers who experienced the greatest smoke exposure had the highest levels of urinary cotinine. Changes in eye and nose symptoms between the beginning and end of the flights were significantly related both to nicotine exposure during the flight and to the subsequent urinary excretion of cotinine. In addition, subjects' perceptions of annoyance and smokiness in the airplane cabin were also related to in-flight nicotine exposure and urinary excretion measures.

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THE ADVERSE health effects on nonsmokers of passive, or involuntary, smoking include lung cancer and respiratory disease, the latter especially among children, as well as acute irritant effects. The scientific evidence for these effects has been reviewed and codified in the Surgeon General's *Report on the Health Consequences of Involuntary Smoking* published in 1986.[1]

Attention recently has been focused on the extent of exposure to passive smoking experienced in various indoor environments where smoking is allowed. The National Academy of Sciences reviewed the data on passive smoking in relation to the quality of indoor air environments in two separate reports also published in 1986. The first is a more general statement, *Environmental Tobacco Smoke: Measuring Exposures and Assessing Health Effects*,[2] and the second, specifically addressing the environment of airline flights, is *The Airliner Cabin Environment: Air Quality and Safety*.[3] The latter recommended a ban on smoking in all domestic commercial flights for four major reasons: to minimize irritation, to reduce health risks, to reduce fire hazards, and to bring air cabin quality into line with standards for other closed environments.

See also p 898.

Public opinion, by smokers and nonsmokers alike, is increasingly in favor of restrictions on smoking in public areas and in the workplace.[4,5] However, there are presently no regulatory standards that specify limits on pollutants affecting air quality in airplanes. Recent legislation in the United States, enacted in April 1988 on a trial basis, has banned smoking on all US carrier domestic flights of two hours or less. The ban is due to terminate in April 1990 unless additional congressional action occurs.[6] In Canada, smoking on flights of two hours or less was banned by the government in December of 1987. Subsequently, both major Canadian airlines voluntarily went beyond the two-hour ruling and banned smoking on all North American flights. One US airline has voluntarily banned smoking on flights of any length within the United States, except flights to and from Hawaii.[6] On Jan 1, 1988, the California legislature enacted a law that banned smoking on all forms of public transportation, including all intrastate airline flights, and limited smoking in transportation waiting areas. Reactions to the ban obtained in a March 1988 survey of 677 passengers and crew showed strong support among nonsmokers (95%) and smokers (57%) (University of San Francisco news release, April 6, 1988).

The Surgeon General of the Public Health Service requested that the Smoking, Tobacco, and Cancer Program of the National Cancer Institute conduct a research study to measure environmental tobacco smoke exposure on typical commercial flights. This study was undertaken (1) to measure nicotine levels in ambient air during flights of approximately four hours' duration and urinary cotinine levels at various points during the three days after the flights, and (2) to determine if these exposure and excretion measurements correlate with each other and with acute symptoms experienced during the flights.

METHODS

Subjects and Procedures

Nine subjects (four attendants and five passengers) participated on each of four flights. Based on smoking chamber data,[7] we determined that this study design would have 77% power for finding a difference in urinary cotinine excretion between subjects moderately exposed to environmental tobacco smoke and unexposed subjects. All subjects were nonsmokers; were not regularly exposed to smoke; were free of chronic respiratory disorders such as asthma, bronchitis, or emphysema;

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Reprint requests to the National Institutes of Health, National Cancer Institute, Division of Cancer Prevention and Control, 9000 Rockville Pike, Executive Plaza North, Room 330, Bethesda, MD 20892 (Dr Mattson).

- Summary of US smoking ban in flights
- International status

Table 1.—Inflight Nicotine Exposure*

Variable	Flight 1	Flight 2	Flight 3	Flight 4
Attendants				
1	3.0 (S†)	6.8 (S)	0.7 (NS)	7.7 (NS)
2	0.1 (NS)	9.4 (NS)	0.5 (S)	9.5 (S)
3	9.8 (NS)	0.2 (NS)	1.5 (S)	7.5 (S)
4	0.9 (S)	10.5 (S)	1.4 (NS)	5.4 (NS)
Passengers				
5	16.6 (S)	0.8 (NS-B)	5.5 (NS-B)	12.9 (S)
6	58.6 (S)	0.1 (NS-B)	32.1 (S)	27.3 (NS-B)
7	0.1 (NS-B)	3.5 (S)	2.5 (NS-B)	8.4 (S)
8	0.6 (NS-B)	0.3 (S)	8.3 (S)	71.0 (NS-B)
9	0.2 (NS-B)	12.6 (S)	27.5 (NS-B)	11.4 (S)
Average No. of smokers per count (No. of observations)	4.2 (9)	3.9 (7)	4.4 (7)	4.4 (5)

*Nicotine values from personal monitoring pump (assigned work or seating area). Values were adjusted for sampling time during which smoking was allowed. Units are micrograms per cubic meter (μg/m³).
†S indicates smoking section; NS, nonsmoking section; and NS-B, borderline between smoking and nonsmoking sections.

were willing to be assigned to the smoking section of aircraft; and volunteered to participate in the study. The protocol was approved by the human subjects institutional review board of the National Institutes of Health and by the participating airline. Eight of the nine subjects were recruited from Air Canada employees.

Data collection for the entire study took place over a 19-day period in May of 1988. The flights' schedules were as follows: flight 1, Toronto to San Francisco; flight 2, San Francisco to Toronto; flight 3, Toronto to Vancouver; and flight 4, Vancouver to Toronto. Seventy-two hours elapsed between all flights except flights 2 and 3, which were separated by four days. Flights 1 and 2 were on B727 jets with 100% fresh air. Flights 3 and 4 were on B767 jets with 50% of the air recirculated.

The same subjects participated in all four flights. The five passenger subjects (three men and two women) were seated in the smoking section or in the nonsmoking section bordering the smoking section. The four attendant subjects (three men and one woman) were assigned to work in smoking or nonsmoking sections of the cabin. All subjects rotated exposure conditions over the four flights, shown in Table 1.

Each flight had four smoking section rows, consisting of 24 seats in flights 1 and 2 and 28 seats in flights 3 and 4. There were 78 seats in nonsmoking in flights 1 and 2 and 93 in 3 and 4. Although the smoking section was fully occupied on the first three flights and there were only two empty seats on the fourth flight, some passengers in the smoking section did not smoke, eg, study subjects and children. Logistical considerations (ie, the airline's need for a rapid turnaround of aircraft) prevented a direct count of all cigarette butts produced by smokers on the flight. Smoking activity was estimated by the field coordinator, who observed the smoking section at intervals throughout the flight and counted the number of persons smoking each time.

The concentration of nicotine in the cabin air was used as a marker or surrogate for the exposure to environmental tobacco smoke. During the flights, nicotine was collected from the air by active sampling as described elsewhere.[9] A personal exposure monitor consisting of a pump sampling at 3 L/min through a cassette containing two filters was used. The first filter collected particles for a separate study of mutagenicity of extractable organics to be reported elsewhere. The second filter was treated with sodium bisulfate to collect the nicotine. The nicotine on the treated filters was desorbed in solvents and analyzed by gas chromatography with nitrogen-selective detection. The sensitivity was 0.07 μg of nicotine per cubic meter. Each subject wore an active sampling system during each flight to measure his or her actual nicotine exposure ("in-flight exposure").

Exposure to cigarette smoke between flights was monitored with both a diary, in which subjects recorded the extent and duration of exposure outside of the flights, and with a passive monitor. For 72 hours before and after each flight, each subject wore a small, lightweight passive monitor that contained a bisulfate-treated filter that collected nicotine by diffusion. These filters were also analyzed by gas chromatography with nitrogen-selective detection.[9,10]

In addition to a preboarding baseline urine sample, subjects collected all their urine for each of 12 six-hour periods after the flight. They recorded the total volume collected for each six-hour period and took a sample from the pooled specimen. All samples were shipped in dry ice to the testing laboratory and analyzed for cotinine and creatinine. The method of cotinine analysis was radioimmunoassay, as described by Haley et al.[11,12] All cotinine values were normalized by creatinine excretion.

Before each flight, all subjects were asked to complete a simple questionnaire about the following symptoms: eyes (itching, burning, dryness, teariness, or increased blinking); nose (dryness, itching, discharge, obstruction, or stuffiness); dry mouth; coughing; sneezing; scratchy or sore throat; and headache. These same questions were asked at the completion of each flight along with additional questions concerning annoyance from cigarette smoking during the flight ("During this flight, were you annoyed or irritated by cigarette smoke?") and an estimate of how smoky the flight appeared to be ("How smoky was the area of the plane in which you spent most of your time?").

Data Analysis

Air nicotine concentrations (in micrograms of nicotine per cubic meter of air) were corrected for the sampling time during which smoking was permitted and the pumps activated. The lengths of time the air sampling equipment was on were as follows: flight 1, 4.8 hours; flight 2, 4.5 hours; flight 3, 4.0 hours; flight 4, 3.8 hours. Since all flights had minimal time during which smoking was curtailed, these corrections were minor. Levels of air nicotine were classified as "high" (>12 μg/m³), "moderate" (1 to 12 μg/m³), or "low" (<1 μg/m³). Statistical significance was assessed by the Wilcoxon-Mann-Whitney rank test[13] and the Mantel linear trends test.[14] Both one- and two-tailed *P* values have been used, depending on whether the direction of the statistical comparison could be anticipated from prior knowledge.

Two types of analyses were done with the urinary data. In the first analysis, the relationship between air nicotine exposure during the flight ("in-flight exposure") and cotinine excretion over the 72-hour period after the flight was examined. Twenty-four–hour moving averages, ie, an average of the four cotinine values for a consecutive 24-hour period, were created to smooth out variability.[15] The cotinine moving average (MA) was computed for the mean cotinine values, normalized for creatinine in units of nanograms of cotinine per milligram of creatinine as follows (where UCP indicates urine collection period

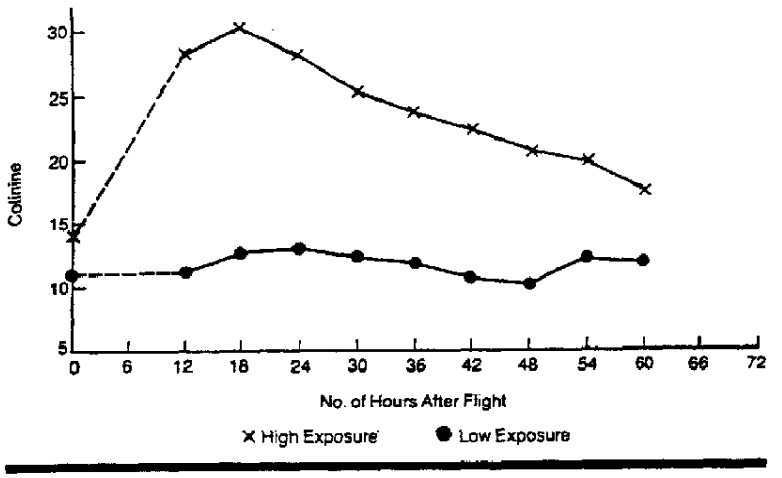

Fig 1.—Cotinine excretion over time. Twenty-four–hour moving average of cotinine excreted after flight. Value at $t = 0$ is average urinary cotinine before boarding flight. High in-flight exposure is defined as nicotine exposure greater than median value. Units are nanograms of cotinine per milligram of creatinine. See text for description of methods.

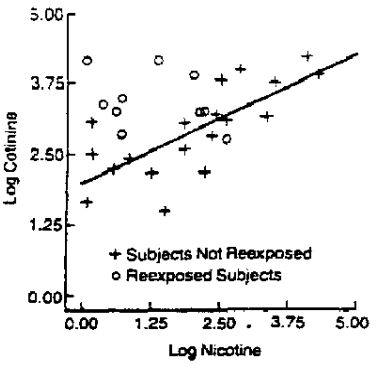

Fig 2.—In-flight nicotine exposure and cotinine excretion at 12 hours after flight. Values are natural logarithms of air nicotine (Ln [nicotine + 1]) and creatinine-normalized cotinine (Ln [cotinine + 1]). Regression line through data points for subjects not reexposed between flights, correlation coefficient = .74, $P = .0003$.

for the stated interval): MA (at 12 hours) = UCP (0 to 6 hours) + UCP (6 to 12 hours) + UCP (12 to 18 hours) + UCP (18 to 24 hours) divided by four, plotted at $t = 12$, the midpoint of that 24-hour interval. MA (at 18 hours) = UCP (6 to 12 hours) + UCP (12 to 18 hours) + UCP (18 to 24 hours) + UCP (24 to 30 hours) divided by four, and similarly for the remaining moving averages. Computed in this way, the 12 postflight urine collection periods yielded a single moving average curve consisting of nine points. Measured levels of in-flight air nicotine were partitioned into those above and below the median value for all flights. Twenty-four–hour moving averages of cotinine levels were plotted against time separately for subjects receiving high (above median) and low (below median) in-flight exposure.

In the second analysis, the dose-response relationship between nicotine exposure and cotinine excretion at 12 hours was examined by scatter plots of in-flight exposure vs cotinine excretion using log-transformed values for all nicotine and cotinine measures. The total number of urinary points available for $t = 12$ hours was 29 (instead of 36), due to missing data.

Linear plots of both raw and creatinine-normalized measures of urinary cotinine and plots of the log-transformed urinary cotinine data (original units were nanograms per milligram of creatinine) done early in the analysis revealed marked variation for some individuals. Some began a flight with unexpectedly high baseline values. For some subjects, peak excretion of cotinine occurred at irregular intervals, with some subjects peaking early, others late, and some showing multiple peaks. The most likely explanation for the patterns observed is that some subjects were reexposed while not on a flight.

The possibility of reexposure was analyzed by examination of the interflight nicotine badge worn between flights and the exposure diaries. Subjects whose passive nicotine badge values indicated exposure of 0.13 μg of nicotine or greater during the 72-hour between-flight interval were considered to have received at least moderately high reexposure. Data from the diaries documenting the day and time of exposures were used in combination with known half-life values for cotinine to determine which collection intervals were affected. The mean baseline cotinine level (nanograms of cotinine per milligram of creatinine) of subjects with interflight badge values of 0.13 μg of nicotine or greater was 34.3, and 12.1 for those with badge values of less than 0.13 μg of nicotine.

Urine samples collected after the following flights were considered unsuitable for analysis due to occurrence of interflight exposures to tobacco smoke: all data for attendant subjects 1 and 2, flights 3 and 4 for attendant subject 3, flight 1 for attendant subject 4, flight 4 for passenger subject 5, and flight 3 for passenger subject 8. These reexposed subjects were excluded from some analyses (Fig 1).

Both questions about symptoms and the questions concerning annoyance and smoke levels experienced during the flight were recorded on a six-point scale from zero to five. Differences in the symptom scores before and after the flight were calculated and categorized into three groups of roughly equal size, coded as 0, 1, and 2. For eye and nose score changes, −2 to 0 was classified as none or mild, 1 to 2 as moderate, and 3 to 4 as marked. For "annoyed" and "smoky," the corresponding categories were 0 to 2, 3, and 4 to 5. A logarithmic transform for both the nicotine values from the personal sampling pumps and the urinary cotinine values was used.

These coded symptom score changes were related to the nicotine and cotinine values by linear least squares regression with the continuous measurements (air nicotine or urinary cotinine) treated as the response variables. The analysis for the self-reported symptoms used *all* subjects and was based on those urinary cotinine values obtained at 12 hours after the flight, not moving averages. Twelve hours was chosen as an appropriate point where there was minimal contamination from reexposure to smoke experienced later during the data collection period.

RESULTS

In-flight Nicotine Exposure

Subject placement and exposure conditions for the four flights along with in-

flight nicotine measurements of air concentrations from the active personal exposure monitors worn in-flight are shown in Table 1. Measurable exposure to environmental tobacco smoke occurred for all subjects on all four flights. Review of the in-flight logs kept by the study field coordinator of counts of smokers done at least hourly indicates a maximum of eight smokers at any one time during the flight, with the average number of smokers per count ranging from 3.9 to 4.4 (Table 1). Table 2 also shows the frequency distribution of the in-flight nicotine readings and levels of statistical significance for various group comparisons.

The personal exposure monitors of subjects on flights with 100% fresh air (1 and 2) recorded less exposure than those on the two flights with 50% fresh air and 50% recirculating air (3 and 4), a statistically significant difference by both tests, with two-tailed *P* values. On flights 1 and 2, all passengers seated in the nonsmoking section (five samples) were exposed to less than 1 $\mu g/m^3$ of nicotine with a median exposure of 0.2 $\mu g/m^3$, while all passengers seated in the nonsmoking section of flights 3 and 4 (five samples) were exposed to more than 2.5 $\mu g/m^3$ of nicotine, with a median exposure of 27 $\mu g/m^3$. Flight 4 from Vancouver to Toronto had the highest levels of air nicotine, with all exposed to greater than 5 $\mu g/m^3$.

Passengers in the nonsmoking border section experienced variability in their exposure, with some attaining exposures comparable to or higher than those in the smoking section. The three highest nonsmoking border readings (27.3, 27.5, and 71 $\mu g/m^3$) were obtained on the flights with 50% recirculating and 50% fresh air. There was also a difference in spatial configuration of the seating between the two types of aircraft. *All* nonsmoking border readings on flights with recirculated air were greater than *all* nonsmoking border values on flights with 100% fresh air. The differences between exposures in the nonsmoking border and smoking sections were not statistically significant. No passenger subjects in the study were placed in the center of the nonsmoking section far from the border with smoking because of the expectation that exposures there would be very low.

Exposure among attendants was not statistically different from that of passengers, although none of the eight high exposures observed on the flights occurred among attendants (Table 2). Exposure among attendants assigned to work in the smoking section was not different from that among those working in the nonsmoking section.

Table 2.—Frequency Distribution of Air Nicotine Readings and Tests of Significance*

Pairs Being Compared	High	Moderate	Low	Significantly Different?	P† WMW	P† MLT
Flights 1 and 2	3	6	9	Yes	.054	.040‡
Flights 3 and 4	5	11	2			
Attendants	0	11	5	No	.15	.093‡
Passengers	8	6	6			
Passengers in smoking section	5	4	1	No	.075	.058§
Passengers in nonsmoking border	3	2	5			
Attendants in smoking section	0	6	2	No	.26	.30§
Attendants in nonsmoking section	0	5	3			

*All readings are from personal pump monitors worn by all subjects during the flights. Units are micrograms per cubic meter ($\mu g/m^3$). High = >12 $\mu g/m^3$; moderate = 1-12 $\mu g/m^3$; and low = <1 $\mu g/m^3$.

†*P* values are from the comparison between the members of each of the pairs indicated. Listed are the *P* values for the Wilcoxon-Mann-Whitney test (WMW) and Mantel linear trends test (MLT).

‡Two-tailed *P* value.

§One-tailed *P* value.

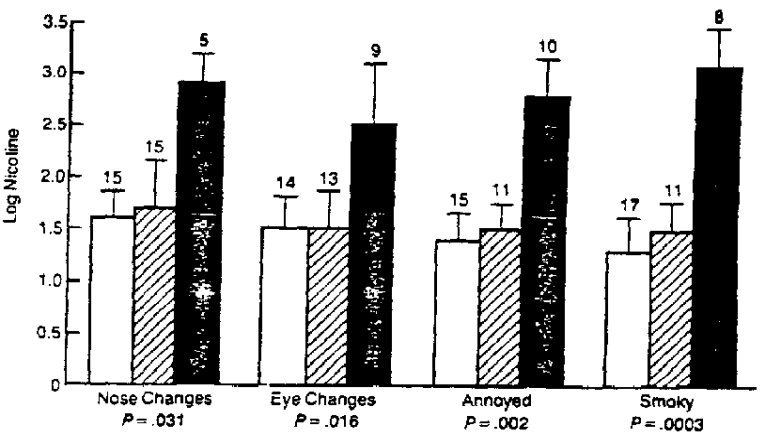

Fig 3.—Relationship of in-flight levels of air nicotine measured by personal monitoring pump to symptoms and perceptions during flight. Units are micrograms of nicotine per cubic meter (log transformed: Ln [nicotine + 1]). Numbers of subjects in each category are shown above bars representing 1 SE. Black bars indicate marked changes; striped bars, moderate changes; and white bars, no or mild changes. *P* values are one-tailed. See text for description of scoring system.

Urinary Cotinine Excretion

Postflight urinary cotinine excretion over time in subjects without appreciable reexposure between flights is shown in Fig 1. A median split was performed on the in-flight nicotine exposure values to divide these subjects into "high" and "low" nicotine exposure groups. The median nicotine exposure value was 5.5 $\mu g/m^3$. The urinary cotinine level for each exposure group was plotted against time using a moving 24-hour average. In the high-exposure group, cotinine excretion increased quickly from preflight levels, rose to a peak value, and monotonically decayed back to a value slightly above the preflight levels by 72 hours. Similar plots of cotinine excretion over time for only the reexposed subjects showed highly elevated baselines, irregular excretion time courses, and no relationship to in-flight nicotine exposure.

Scatter plots of all data using different symbols to distinguish reexposed subjects were done to investigate dose-response relationships (Fig 2). Urinary cotinine excretion (creatinine corrected) at 12 hours after the flight for subjects not reexposed showed a clear correlation with nicotine exposure received during the flight. The correlation coefficient was .74 with $P = .0003$. There was no significant correlation between the cotinine and nicotine values for the reexposed subjects.

Self-reported Symptoms

Dry mouth, coughing, sneezing, scratchy or sore throat, and headache were not significantly related to nicotine exposure. On the other hand,

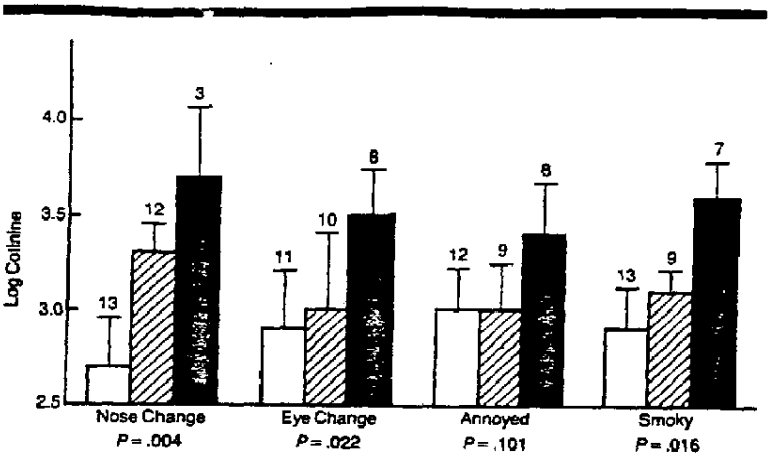

Fig 4.—Relationship of urinary cotinine excretion at 12 hours after flight to symptoms and perceptions during flight. Units are nanograms of cotinine per milligram of creatinine (log transformed: Ln [cotinine + 1]). Numbers of subjects in each category are shown above bars representing 1 SE. Black bars indicate marked changes; striped bars, moderate changes; and white bars, no or mild changes. *P* values are one-tailed. See text for description of scoring system.

changes in eye symptoms, nose symptoms, annoyance with smoking, and perception of a smoky environment were all related significantly to the nicotine exposures. These relationships are illustrated in Fig 3.

As with the nicotine analysis, no significant relationships were seen between the 12-hour log-transformed urinary cotinine values and dry mouth, coughing, sneezing, scratchy or sore throat, or headache. Like the nicotine data just described, these urinary cotinine data also showed significant relationships to eye and nose symptom changes as well as to the perception of the smokiness in the aircraft cabin (Fig 4). The relationship for the annoyance index was not statistically significant, but the observed changes were in the expected direction. Some evidence suggests that changes in eye symptoms may have been more marked in the two subjects wearing contact lenses.

COMMENT

Several other studies have measured air nicotine levels in indoor environments and report that a wide variety of factors act in combination to produce a particular "microenvironment." Differences in methodology, such as type of monitoring devices and assays, ventilation, selection of sampling times and number of smokers present, and their location relative to sampling devices, all limit precise comparisons across these studies. However, the levels of nicotine found in this study are comparable to the measurements reported in other studies shown in Table 3 and support the conclusion that air nicotine levels in the nonsmoking areas that border the smoking area may be at least as high as in similar indoor environments frequented by smokers.

A small number of studies have been published in the scientific literature that assess environmental tobacco smoke specifically on board aircraft. These studies have assessed exposure by measuring concentrations of carbon monoxide,[16,17] particulates,[16] and nicotine,[18-20] with one also assessing physiological absorption (ie, blood nicotine) resulting from exposure.[17] The results from the two studies employing in-flight nicotine measurements are summarized in Table 3.

In this study, air levels of nicotine were highly variable, with some nonsmoking areas attaining levels greater than those in some smoking sections. Seating section was a less important predictor of actual nicotine exposure. This bears out travelers' anecdotal observations that the section in which one sits is often not as important in determining exposure to smoke as is the environment generated by one's neighbors. This environment is determined by several factors, including the number of cigarettes smoked by neighbors, seating configuration, air flow patterns, and the percentage of recirculated air. In these flights, the average number smoking at any one time was only about four and was never observed to be greater than eight. This may represent relatively low exposure compared with flights with many more smokers.

The type of ventilation appeared to be an important factor in the levels of air nicotine attained. Planes with 100% fresh air (flights 1 and 2) had significantly less ambient nicotine than those with 50% fresh air and 50% recirculating (flights 3 and 4). Recirculation systems significantly increase the fuel economy and so are an integral part of the design of some newer aircraft. Passengers and attendants may be exposed to higher levels of environmental tobacco smoke in the next decade as the percentage of seat-hours on airplanes with recirculation systems increases from 30% in 1985 to an estimated 40% in 1990.[4]

Attendants are not confined to the section in which they are assigned to work and move through all areas of the plane. Although the attendants were assigned either to the smoking or nonsmoking sections, in fact there were only about four rows of smokers on each of the four flights and the attendants worked in both smoking and nonsmoking areas when they were assigned to the smoking area. Attendants assigned to nonsmoking areas may have received exposure from the first-class smoking section and from passing through the

Table 3.—Air Nicotine Levels (μg/m³) in Various Indoor Environments*

Environment		Mean	Range
Airplanes†	(NS)	14 (median = 2)	0.1–71
	(NSa)	4 (median = 3)	0.1–10
	(S)	17 (median = 12)	0.3–59
	(Sa)	5 (median = 5)	0.7–11
Airplanes‡	(NS)	7 (geom = 3)	ND–24
	(NS)	13 (geom = 8)	ND–40
	(NS)	8 (geom = 4)	ND–17
	(S)	11 (geom = 7)	0.4–42
	(S)	30 (geom = 7)	ND–112
	(S)	26 (geom = 22)	ND–77
Airplanes§		15	5–29
Trains‖		...	0.7–50
Offices‖		0.9	14 (peak)
Offices§		19	9–31
Offices¶		...	3–28
Pubs, coffee shops‖		...	25–52
		5	...
		10	...
Cafeterias§		26	12–42
Lobbies, waiting rooms‖		37	...
		7	...
		1	...
		3	...
Automobiles‖			
Open ventilation		85	...
Closed ventilation		1010	...
Room‖		500	...
Submarines‖		15–35	...

*NS indicates nonsmoking section; S, smoking section; NSa, nonsmoking section (attendants); Sa, smoking section (attendants); and ND, not detectable.

†This report.

‡Oldaker nonsmoking values were measured at or near the border with smoking in three different types of planes. Arithmetic means were presented originally[16]; geometric means (geom) were subsequently published.[18]

§Muramatsu et al.[18]

‖Summary across studies taken from National Academy of Sciences review of studies reported in the literature between 1957 and 1980.[1] The number of studies cited in the report are as follows: trains, three; offices, one; pubs etc, three; lobbies etc, four; automobiles, one; rooms, one; and submarines, one.

¶Hammond et al.[3]

smoking section in coach. This may explain why there was no significant difference in exposure between attendants assigned to the two sections.

Although the levels of exposure of attendants measured by the personal exposure pumps were less than those of passengers (although not statistically significant), the amount of nicotine and other cigarette smoke products actually inhaled and ingested may have been greater due to the greater physical activity and increased respiratory rate of the attendants. If true, this, together with the cumulative exposure attained from long periods of flight duty, could result in greater total exposure over the course of an attendant's career.

The levels of environmental tobacco smoke that occurred during the four-hour flights led to increased levels of cotinine (a major metabolite of nicotine) in the urine of both passengers and attendants. Subjects who experienced the greatest in-flight nicotine exposure generally had the highest levels of urinary cotinine and continued to excrete cotinine for 72 hours after the flight. The shape and time course of the decay pattern are consistent with a first-order pharmacokinetic decay process following an initial exposure to nicotine. The peak level of cotinine excreted is related to the dosage of nicotine received over the range of exposures encountered.

Reports on dose-response data under conditions of environmental tobacco smoke exposure are sparse, especially for the nicotine concentration range typically encountered by nonsmokers under free-living conditions. This analysis provides estimates of the response to a bolus of environmental tobacco smoke, delivered over a four-hour period, shown by a subsequent increase in urinary cotinine excretion over time synchronized across subjects. This study expands upon previous studies employing single-point estimates of cotinine or self-reported smoke exposure levels[21-28] and provides information on the shape of the excretion curve, delay to peak, amplitude to the peak, approximate functional form, and decay time of cotinine excretion after environmental tobacco smoke exposure.

Changes between the beginning and end of the flights in eye and nose symptoms indicative of acute irritation are related both to a measure of in-flight nicotine exposure and to the later urinary excretion of cotinine. In addition, perceptions of annoyance and smokiness in the airplane cabin were likewise related to the in-flight nicotine exposure and urinary cotinine excretion measures. Experimental studies under controlled conditions indicate that in smoky environments, eye, nose, and throat symptoms gradually increase over time with the duration of exposure even when smoke concentrations remain constant. Annoyance tends to rise quickly as soon as exposure begins and then remain constant over time.[26] The irritant effects of cigarette smoke are reflected in the numerous complaints about smoky conditions by attendants and passengers alike in records compiled by the Association of Flight Attendants and in government and industry surveys.[3,16,27-29] In these surveys, 60% of nonsmoking passengers and 15% of smokers reported being annoyed by in-flight tobacco smoke.[16] Ninety-five percent of cabin attendants reported irritation and annoyance,[27-29] with 69% in one study[29] perceiving smoky air to be a more serious concern than other work environment conditions such as temperature, odors, dust levels, and noise.

Taken together, data from this study on in-flight nicotine exposure, subsequent cotinine excretion, and acute symptoms demonstrate that total separation of smoking and nonsmoking sections was not achieved on the flights studied. The exposures experienced by passengers and attendants are comparable to those in other closed environments where smoking is allowed and represent another contributor to the cumulative health risk, acute irritation, and annoyance that nonsmoking individuals receive from passive smoking.

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— cotinine data analysis unclear, should address this question